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Short Period Dispersion Management of 160 Gb/s Single Channel Fiber System

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Abstract *A transmission distance of 7500 km is numerically predicted for 160 Gb/s single channel fiber systems by using realistic dispersion parameters of ± 6 ps/nm/km. System tolerance on third order dispersion and optical filtering is investigated.*

Introduction

The idea of short period dispersion management (DM) based on short lengths of fibers which alternatively have opposite dispersion sign is attracting increasing attention because of its powerful soliton-like characters. In such a dispersion managed system, the average dispersion in each span is close to zero and the input peak power is enlarged, which both reduces Gordon-Haus jitter effects and improves signal to noise ratio simultaneously. This enables single channel transmission at high bit rates at 160 Gb/s and above. There is considerable theoretical and experimental research going on at that bit rate [1-5]. Up to now, numerical simulations have predicted about 8000 km transmission distance with dispersion parameters D= ±1 ps/nm/km [4], but it is very difficult to produce fibers with such a small dispersion because of the small allowed tolerances in the fiber geometry.

In this work, we consider dispersion parameters of ±6 ps/nm/km. Such values can be controlled realistically in production. We predict a transmission distance of 7500 km neglecting polarization mode dispersion (PMD) and Raman effects. It is found that system performance is very sensitive to third order dispersion (TOD) and that an optical filter can significantly reduce timing jitter due to pulse-to-pulse interaction.

System model

Gaussian input pulses are used in a PRBS sequence of length 2^{10}-1 transmitted at a wavelength of 1550 nm. Each fiber span is 50 km long and its loss is fully compensated by an optical amplifier with a noise figure of 4.5 dB. An in-line Gaussian optical bandpass filter is inserted after each amplifier. We have found by numerical simulation that the filter optimal bandwidth is 870 GHz. An electrical low-pass Bessel filter with a bandwidth of 0.7 times the bit rate is used at the receiver. Anomalous dispersion fiber with dispersion of 6 ps/nm/km, dispersion slope of 0.03 ps/nm^2/km, attenuation of 0.2 dB/km, effective area A_{eff} of 50μm^2 and normal dispersion fiber with corresponding parameters equal to -6 ps/nm/km, 0.03 ps/nm^2/km, 0.25 dB/km and 45 μm^2 are used. The nonlinear index is the same for both fibers and is taken equal to 2.6×10^{-20} m^2/W.

The dispersion map in one amplifier span is determined by the map strength S which plays a key role in controlling the pulse breathing. S is given by $S = \frac{|\beta_{21} L_1 - \beta_{22} L_2|}{T_{FWHM}^{\ 2}}$, where L_1 and L_2 denote the lengths and β_{21} and β_{22} the group velocity dispersion (GVD) parameters of anomalous and normal dispersion fiber, respectively. T_{FWHM} is the full-width half-maximum of the input pulse. We use the optimal value of S=1.6 [1] in our dispersion maps to avoid too strong pulse breathing which can generate dispersive waves that can destroy the balance of nonlinearity and dispersion. Fibers with opposite dispersion signs are placed alternatively in the amplifier span. Each fiber length is about 235 m. The average dispersion $D_{ave} = \frac{|D_1 L_1 + D_2 L_2|}{L_1 + L_2}$ is chosen to be near zero. Fiber splicing loss inside the spans is neglected in our investigation.

Simulation results

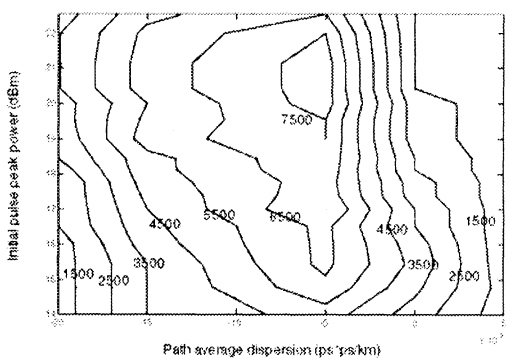

Fig. 1 Maximum transmission distance for a BER of 1x10^{-9} as a function of path average dispersion and pulse input peak power.

In Fig. 1 we show the maximum transmission distance which can be reached for a bit-error-rate better than 1x10^{-9} for different path average dispersions and initial pulse input peak powers. It can be clearly seen that the optimum path average dispersion is located in the anomalous range, where the system performance is much better than in the normal dispersion range. At β_{2ave} = -0.005 ps^2/km, we get the best result of 7500 km, where nonlinearity counteracts dispersion perfectly, keeping pulse evolution regular and soliton-like.

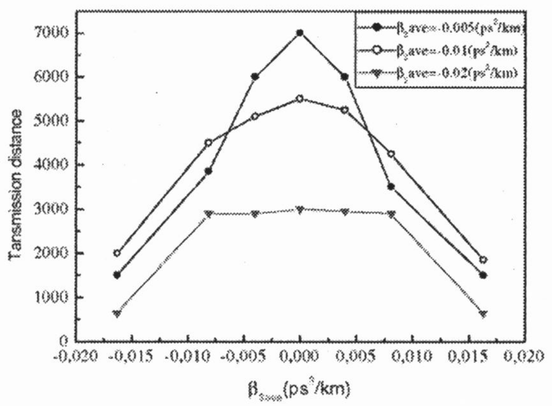

Fig. 2 Transmission distance as a function of the average third-order dispersion β_{3ave} for different values of the average dispersion parameter β_{2ave}.

We have investigated the third order dispersion tolerance for system stability against changing fiber dispersion slope. Here β_{3ave} denotes the average third order dispersion β_3 in one span. From Fig. 2 we find that the transmission distance for β_{2ave}=-0.005 (ps^2/km) will be decreased to 6000 km (which is 85% of the maximum distance of 7000 km) when β_{3ave} varies in the ±0.004 (ps^3/km) range. Outside this range the system is very sensitive to changes in β_{3ave} and the transmission distance decreases rapidly. However, for β_{2ave}= -0.01 (ps^2/km), the range of β_{3ave} with transmission reduced to 82% increases to ±0.08(ps^3/km), and for β_{2ave} = -0.02 (ps^2/km), the range of β_{3ave} increases to ±0.01(ps^3/km) which gives very stable transmission performance. Therefore, our simulations show that the TOD tolerance range is within ±0.01 ps^3/km and, as expected this range increases with larger average dispersion. It can also be seen that for a given transmission distance, the maximum TOD tolerance depends on the optimum average dispersion.

We have also studied the influence of having an in-line filter in each amplifier span. The results are shown in Fig. 3 where we present the calculated BER as a function of the number of spans in the following cases: a) without noise and without filter, b) with noise and with filter, c) without noise and with filter, in order to assess whether the benefits were arising from noise filtering or from a reduction of pulse-to-pulse interaction. Comparing eye diagrams a) and c), it is clear from Fig. 3 that without filter, timing jitter becomes a serious problem even without accumulated amplifier spontaneous emission (ASE).

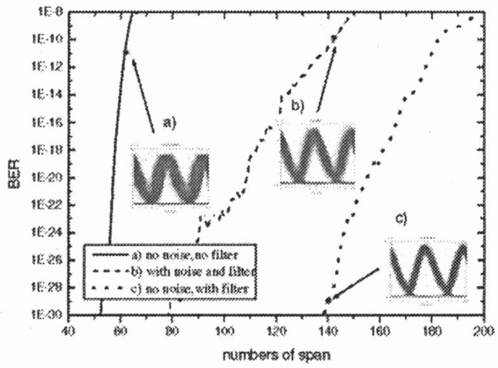

Fig. 3 Calculated BER as a function of the number of spans with and without in-line filter.

This means that pulse-to-pulse interaction is the main limiting factor that deteriorates such a dispersion managed system. An optimised filter with a bandwidth of 870 GHz can surprisingly improve the transmission distance by a factor of two. That is because phase shifts between neighbouring pulses, which cause pulses interaction by accumulation, can be destroyed by the filter. From eye diagram b) it can be understood that noise enlarges the timing jitter not only by adding a random component to the signal spectrum but also by causing random fluctuations in phase change between neighbouring pulses. Our results show that a filter can greatly reduce pulse-to-pulse interactions and hence suppress the timing jitter effectively.

Conclusion

We have shown by numerical simulations that short period dispersion management is very promising for high speed long haul systems. A distance of 7500 km was obtained using alternating dispersion of ±6 ps/nm/km which is a realistic value from a fiber production point of view. Numerical results also show that although the TOD tolerance is larger when the average dispersion is higher, for a given same distance the maximum TOD tolerance range is dependent on the optimal average dispersion, which is useful information for making experimental designs. We also find that an in-line optical filter is more important for suppressing timing jitter due to pulse-to-pulse interaction than for reducing accumulated ASE.

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